FINITE ELEMENT MODEL OF THE GUILLOTINING PROCESS

H.H. Wisselink[†] and J. Huétink[‡]

[†] University of Twente, Faculty of Mechanical Engineering, Enschede, The Netherlands,
Tel: +31 53 4894346, Fax: +31 53 4893900, email:h.h.wisselink@wb.utwente.nl,

[‡] University of Twente, Faculty of Mechanical Engineering, Enschede, The Netherlands,
Tel: +31 53 4892460, Fax: +31 53 4893900, email:j.huetink@wb.utwente.nl

Abstract: Guillotining is a sheet metal cutting process, in which the sheet is cut progressively from one end to the other. Consequently guillotining can be seen as a three-dimensional stationary process. A finite element model is developed for the calculation of the steady state of this process. To be able to handle history dependent material properties and moving free surfaces an Arbitrary Lagrangian Eulerian formulation is used. The position of the crack front is initially modelled and kept fixed during the calculation. The results of a guillotining simulation are shown in this paper.

Keywords: Guillotining, FEM, ALE, Ductile fracture

1 Introduction

A guillotine-type shear has two straight blades with a clearance between them. When the inclined upper blade is forced downwards the sheet is cut progressively from one end to the other This can be seen as a stationary process (Ignoring the start and the end of the cut). Which will be clear when the dotted box in Figure 1(c) and 1(d) is followed during the process. The angle between the upper and lower blade, the shearing angle α, varies in practice between 0.5°–3°.

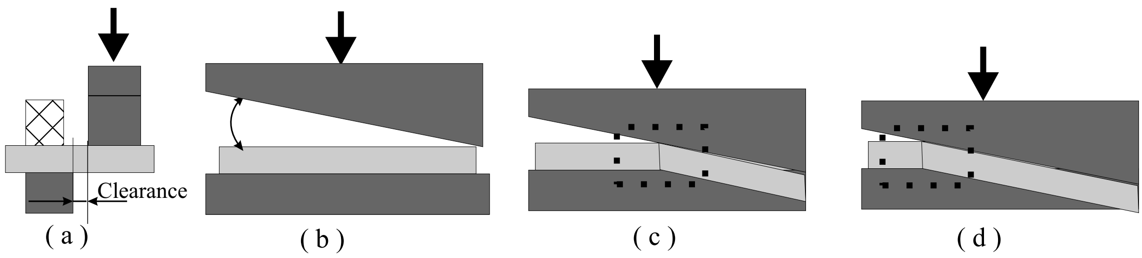


Figure 1. Guillotining

The total deformation consists of two parts, which influence each other. First the sheet is sheared by the downward motion of the blade, causing elastic and plastic deformations, which finally leads to a ductile fracture of the sheet. In the second place, the sheet has to bend to conform to the inclination of the blade. This combination makes guillotining different from blanking.
The objective of a guillotining process is to cut the sheet with a certain edge quality (burr) and flatness with a limited force. The knowledge of the influence of the process parameters on the proces is mainly empirical [1]. To gain more insight in this process, a finite element model is developed to study the influence of some parameters on the guillotining process . The results should contribute to a better process controll.

2 Finite element formulation

Guillotining is a stationary process with history dependent material behaviour and free surfaces. To calculate the steady state of such a process a transient calculation can be carried out until a steady state is reached. For this calculation the ALE method is used. With an ALE formulation free surfaces can be followed and history dependent material behaviour can be taken into account. For the calculations the finite element code DiekA is used, which contains an ALE formulation.

2.1 ALE method

Characteristic for an ALE formulation is that the mesh displacement does not have to be equal to the material displacement. First an Updated Lagrangian step is carried out to calculate the material displacements. Next the grid displacements are determined from the material displacements (section 3.3). The history dependent variables have to be calculated in the new grid points. It can be shown that this is a convection problem. The convection is calculated with the artificial dissipation scheme of Huétink [6], [?]. This scheme is adapted to avoid crosswind diffusion, which works well for flow in mesh direction, as is the case in the simulations.

3 Guillotining model

3.1 Preprocessing

The preprocessing is carried out within PATRAN [?]. A parametric function written in Patran Command Language generates an input file for the finite element code DiekA. The initial mesh is an estimation of the steady state volume around the process zone (the material in the dotted box, figure 1), and is given in figure 3. One part of the sheet is clamped above the lower blade, the part under the moving blade is free (figure 1(a)). The material flows in positive x-direction through the mesh, therefore a displacement is prescribed on the inflow. A penalty method is applied for the contact with the rigid tools [6].

3.2 Material model

An elastic-plastic material model is used, with a Von Mises yield criterion for the plastic flow. Hardening is described with the extended Nadai formula.

$$\sigma_y = \sigma_0 + C(\varepsilon_0 + \varepsilon^p)^n \tag{1}$$

ε_0	$7.1 \cdot 10^{-3}$	C	565.3 Mpa	E-modulus	206 MPa
σ_0	15.7 MPa	n	0.2589	ν	0.3

Table 1. Material properties

The sheet is finally seperated by a ductile fracture process. In the steady state a stable crack front is present which propagates with constant speed. New surfaces are generated by the crack. Atkins [?] puts forward that there exists a zone of combined plastic flow and fracture before the sheet is completely seperated. A crack front is modelled in the initial mesh. The crack front has the same shape as the crackfront in figure 2, giving a zone of combined plastic flow and fracture.

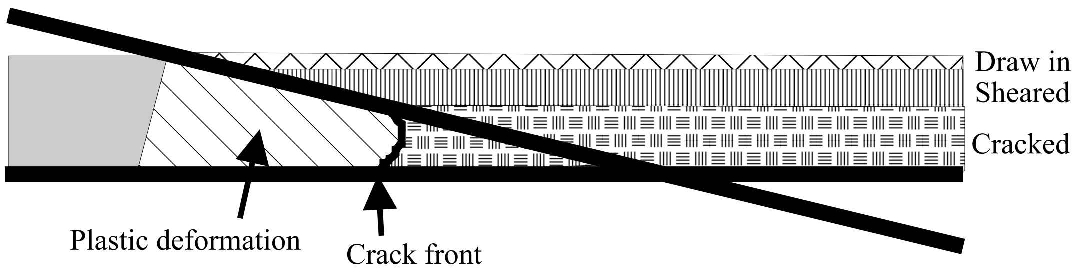


Figure 2. Estimation of the crack front

Some different methods for the simulation of ductile fracture in 2D shearing are proposed by [2],[3], [?] and [5]. They all have in common that cracks initiate/propagate when some fracture parameter reaches a critical value. This means that the state of points on the crack front should be critical (whatever criterion is used) in the steady state. With the ALE method and a fracture model it should be possible to adapt the crack front from an initial estimation to it's steady state position. Condition for this is that the initial shape of the crack front is a good estimation of the steady state shape of the crack front. In the calculations showed in this paper the crack front is spatially fixed.

3.3 Mesh management

When determinating the new positions of the nodes, two things are required. No material should be gained or lost, except for the in- and outflow, and a good element shape should be preserved. A structured 3D mesh of hexahedrals is used, which gives a regular grid on the surfaces. This grid is kept fixed in flow direction (x-direction). Perpendicular to the flow direction (in the yz-plane) the grid follows the movement of the free surface. The new grid positions are determined in the following order:

- First all surface nodes are put back to their original x-coordinate. The new y- and z- coordinates are calculated with a convection scheme, using the coordinates of neighbouring nodes on a gridline in flow direction [**?**].

- Next the surface nodes are repositioned on the surface in the yz-plane, to keep small elements around the tool tips, where the largest deformations are found. The nodes on the tips of the blades are kept on that tip. The other nodes are put so that the initial refinements are kept, using a procedure described by Ponthot [10].

- When the new surface is known the new position of the internal nodes can be calculated. In the process zone a Laplacian smoothing procedure is used. Outside the proces zone the grid displacement of the internal nodes is related to the grid displacement of the nodes on the top and bottom surface.

- Nodes on the crack front are spatially fixed. This means that the surface is not followed, but that the crack propagates.

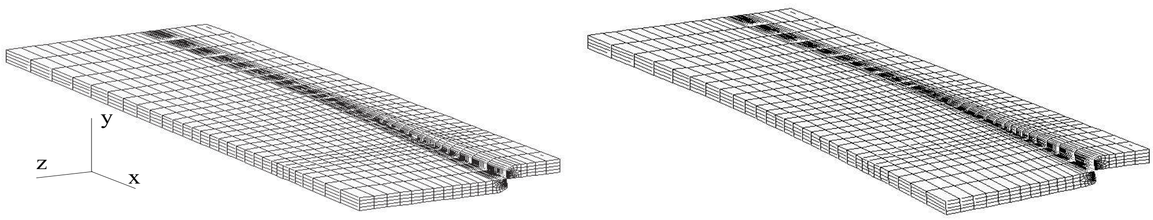
4 Simulation results

Figure 3 gives the initial mesh for the guillotining simulation (Some data are given in Table 2) of which the results are presented. The sheet starts fracturing at a blade penetration of 50% of the thickness of the sheet and is completely separated at 60%. The crackfront is not visible in the finite element meshes.

sheet thickness	1 mm	Number of bulk elements	8640
sheet width	15 mm	Number of contact elements	2220
clearance	10%	Number of independent d.o.f	28611
shearing angle	2.5 °		

Table 2. Simulation data

The resulting steady state geometry is given in Figure 3. The initial shape has evolved to the steady state geometry, where the different zones on a sheared edge, the draw-in, sheared and fractured part, can be recognised (Figure 4). The mesh around the tool tips is too coarse to model the development of a burr. Finer meshes will lead to more accurate results, but take also a lot of time extra.



(a) Initial mesh

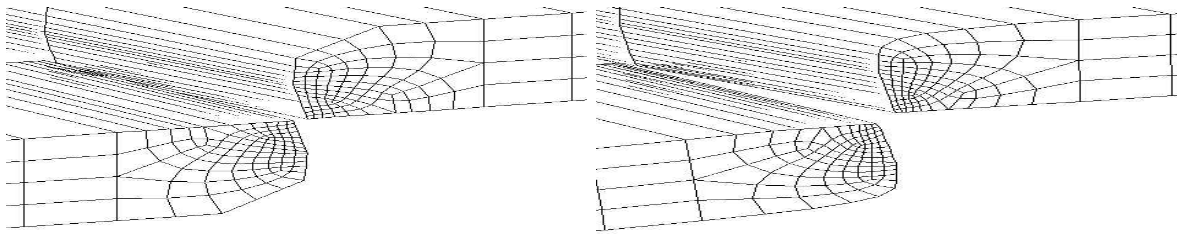
(b) Steady state mesh

Figure 3. meshes

The resulting equivalent plastic strain and hydrostatic pressure in the steady state are shown on a slice of one element length from the complete mesh, just before the crack front starts (Figures 5(a) and 5(b)). At the tip of the blades a state of hydrostatic tension (=negative pressure) with large plastic strain has developed. From literature it is known that this combination probably will cause crack initiation.

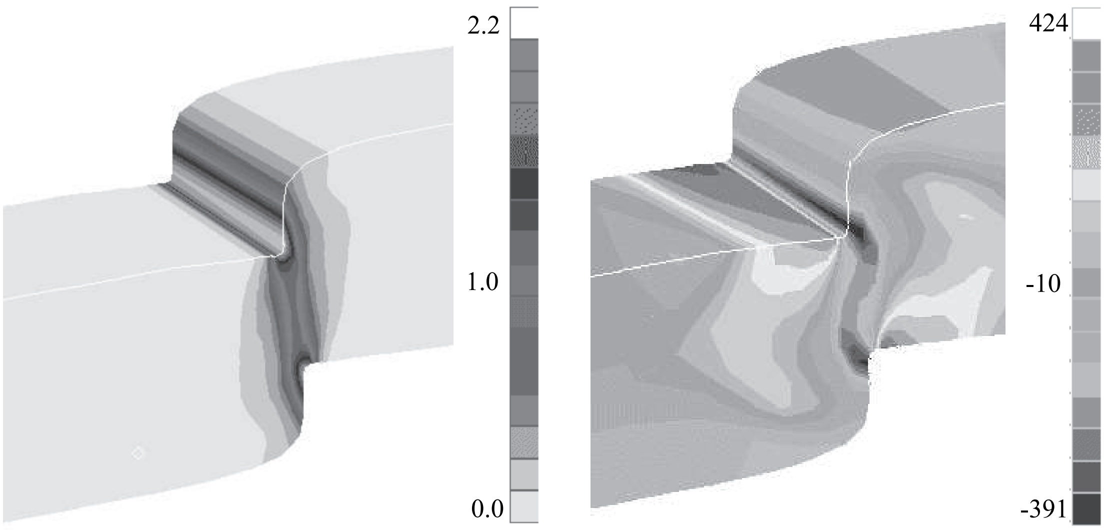
5 Conclusions

The method described in this paper for simulation of guillotining gives a good insight in the process. Free surfaces can be followed and a good element shape is preserved with the ALE formulation. Therefore the model is able to calculate the shape of the sheared edge, residual stresses in the sheet and the twisting of the sheet, given an initial crack front. Because the crack front is not adapted during the calculation, the results depend for a great part on the initial estimation of the crack front. Therefore the model should be improved with a procedure which adapts the position of the crack front according to a fracture criterion.



(a) Initial mesh (b) Steady state mesh

Figure 4. meshes, zoomed in



(a) equivalent plastic strain (b) hydrostatic pressure (MPa)

Figure 5. Results on slices from the steady state mesh

References

[1] H. Sperling, *Blech*, vol. 15, no. 4, pp. 164–169, 1968.
[2] J. Huétink, P. T. Vreede and J. van der Lugt, *Int. j. of Numerical methods in Engineering*, vol. 30, pp. 1441–1457, 1990.
[3] P. N. van der Helm, J. Huétink and R. Akkerman, *Int. j. of Numerical methods in Engineering*, vol. 41, no. 6, pp. 1057–1076, 1998.
[4] MACNEAL-SCHWENDLER, *MSC/PATRAN 7.6*.
[5] A. Atkins, *Philosophical magazine A*, vol. 43, no. 3, pp. 627–641, 1981.
[6] S. Bezzina and K. Saanouni, in *Computational Plasticity, Fund. and Appl.* (D. Owen, E. Onate and E. Hinton, eds.), pp. 611–618, 1997.
[7] L. Morançay, H. Homsi and J. Roelandt, in *Computational Plasticity, Fund. and Appl.* (D. Owen, E. Onate and E. Hinton, eds.), pp. 1065–1070, 1997.
[8] D. Brokken, W. A. M. Brekelmans and F. P. T. Baaijens, *J. of Materials Processing Tech.*, vol. 83, pp. 192–199, 1998.
[9] E. Taupin, J. Breitling, W. Wu and T. Altan, *J. of Materials Processing Tech.*, vol. 59, pp. 68–78, 1996.
[10] H. H. Wisselink and J. Huétink, in *ESAFORM '98* (J. Chenot et al, eds.), pp. 243–246, 1998.
[11] J. P. Ponthot, in *Numerical methods in Industrial forming processes* (E. G. Thompson, ed.), pp. 203–210, Balkema, Rotterdam, the Netherlands, 1989.

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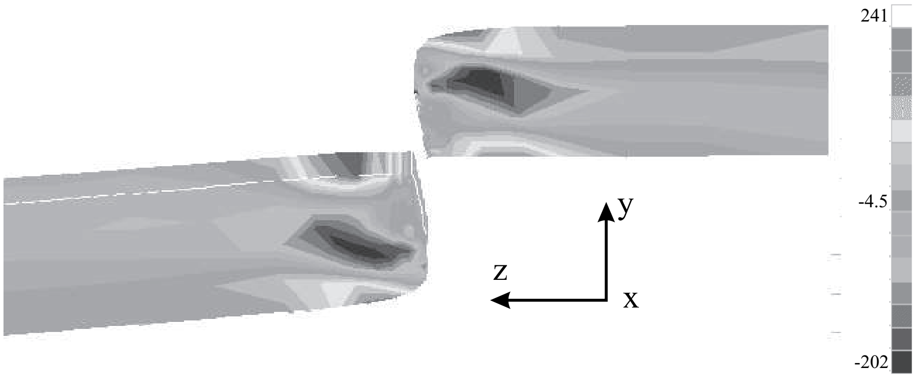
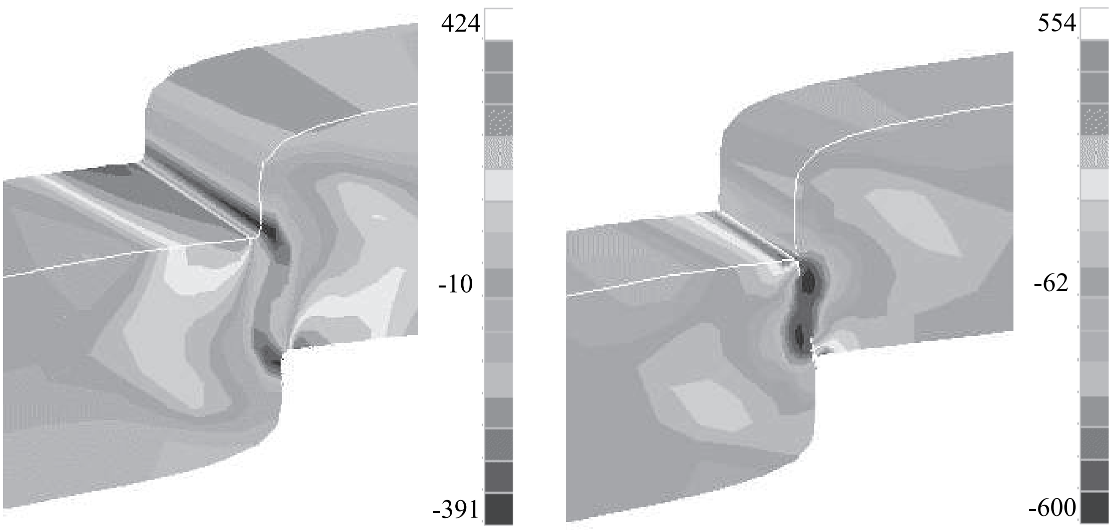


Figure 6. residual stresses: $\sigma_{zz}(MPa)$



(a) slice of just before cracking

(b) slice of combined plastic flow and cracking

Figure 7. hydrostatic pressure (MPa)